Distribution, Abundance and Phenology of *Scaptomyza (Bunostoma) anomala* Hardy (Diptera: Drosophilidae): a Proposed Representative Species for Monitoring Protein Bait Sprays in Hawai'i

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ABSTRACT. The endemic Hawaiian drosophilid *Scaptomyza* (*Bunostoma*) *anomala* is proposed as a representative native species for monitoring the effects of protein bait sprays against pest Tephritidae in Hawai'i. This species is strongly attracted to protein bait and is found on several different islands. On Kaua'i, it occurs from sea level to at least 1200 m elevation and can be found in areas of both native and alien vegetation. In some areas this species displays distinct seasonal fluctuations in abundance, which vary with elevation and habitat. Fly abundance varied significantly both among and within sampling sites, with abundance usually related to the amount of shade, but the relationship varying with elevation and habitat. It is suggested that a monitoring system for this species employ multiple traps in each of several paired treatment and control sites, with a minimum of 1 year pretreatment and 1 year posttreatment data collection.

INTRODUCTION

Perhaps the most controversial aspect of pest tephritid eradication/control in Hawai'i is the possible negative effect on the unique native insect fauna (Howarth 1990, USDA-APHIS 1985). The widespread application of bait sprays is considered particularly questionable due to its non-specificity and therefore the potentially diverse nontarget effect (Beardsley 1990, Asquith & Messing 1992). Although recent eradication strategies have emphasized more environmentally benign techniques such as sterile insect releases (Lance et al. 1992), not even incipient infestations of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), have been successfully eradicated with sterile insects alone, much less established populations such as those in Hawai'i. Therefore, it is likely that any full scale eradication program in Hawai'i would either plan for (Harris et al. 1986), or have to resort to (Jackson & Lee 1985) bait sprays, at least to reduce high populations in agricultural areas.

Despite concerns regarding bait sprays, almost all available environmental data are for pests, predators or parasitoids in agricultural systems. Only during the 1980–1982 California Mediterranean fruit fly eradication program were nonagricultural systems monitored. Direct kill of larval Lepidoptera was documented (Troetschler 1983) and a population surge of a native gall midge (Diptera: Cecidomyiidae) was observed, presumably resulting from bait spray-induced mortality of its parasitoids (Ehler et al. 1984). In the only non-agricultural study of potential bait spray impacts in Hawai'i, Asquith & Messing (1992) found at least 11 species of native litter arthropods that are attracted to protein hydrolysate bait. These studies demonstrate a clear potential for an impact on the native Hawaiian insect fauna and suggest that more detailed information on susceptible species should be evaluated before implementing a large bait spray program.

Just as a pest fruit fly eradication or suppression program would be evaluated by comparing pre- and post-treatment pest numbers, assessment of the environmental effects of such a program should be based on comparable data for native species. Although one cannot foresee which of the thousands of Hawaiian endemic species may be affected, it would be impossible to evaluate the impact on all species and probably impractical to intensive-

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ly monitor even 20 or 30. A more pragmatic approach is to select a few representative species likely to be affected by bait sprays and that can be quantitatively monitored.

As suggested by Asquith & Messing (1992), the drosophilid *Scaptomyza* (*Bunostoma*) *anomala* Hardy is likely to be a susceptible species since it is strongly attracted to protein bait. Unlike most Hawaiian Drosophilidae, which are usually single island endemics, *S. anomala* is found on Kaua'i, Maui and Lana'i, and what is probably its ecological equivalent, *Scaptomyza varifrons* (Grimshaw), occurs on O'ahu (Hardy 1965). This means that the same species and technique could be used for monitoring on different islands.

The objective of this paper is to promote the use of *S. anomala* as a representative species for environmental assessment of large bait spray programs in Hawai'i. Towards this goal, I provide suggestions for monitoring techniques, and present baseline data on the distribution, seasonal phenology and abundance of this species on the island of Kaua'i.

MATERIALS AND METHODS

Scaptomyza anomala was sampled using pitfall traps consisting of 500-ml plastic cups, with a smaller 120-ml cup in the bottom filled with ethylene glycol as a preservative. A plastic funnel was also fit inside the larger cup, rims flush with each other, and a round, 20 cm diameter plastic rain cover supported by nails was placed ca. 5 cm over each trap. The funnel and the surrounding ground within a 10 cm radius of the trap were sprayed with protein bait (NuLure®, Miller Chemical & Fertilizer Corp., Hannover, PA) from a hand held applicator. Traps that were buried to the lip often caught enormous numbers of amphipods or isopods, making it difficult to sort the sample. Traps buried with the lips 2–3 cm above the ground eliminated this problem but did not affect fly captures. The contents of traps were collected and traps rebaited weekly or biweekly.

Eighteen different localities covering a variety of habitats and elevations were sampled on Kaua'i (Table 1). The number of traps and trapping periods varied among localities, but 2 stations, Alexander Reservoir and the Alaka'i, were sampled for 1 and 2 years respectively, to assess the seasonal phenology of the fly. The relationships between fly abundance and monthly rainfall and temperature at these sites were examined with Pearson's correlation analysis. Also at these 2 locations, the microhabitat of each trap was recorded by qualitatively assessing 4 variables: 1) amount of leaf litter; 2) amount of shade; 3) amount of direct sun; and 4) soil moisture. For each trap, variables were scored on a scale of 0–3 (e.g., 0 = no leaf litter; 3 = 100%). The relationship between these variables and fly abundance was analyzed using Spearman's Rank Correlation.

Variation in fly captures among traps was examined by one-way analysis of variance (ANOVA) and means were separated using Duncan's multiple range test.

RESULTS AND DISCUSSION

Elevational and Habitat Distribution

Scaptomyza anomala may be the most ubiquitous species of native Drosophilidae on Kaua'i, as it was collected from almost sea level to 1200 m (Table 1). Despite intensive efforts to collect larvae and rear adults from substrates, the larval habitat was undetermined. However, this species does not appear to be substrate specific as are many other native Hawaiian Drosophilidae (Heed 1968). It was collected from wet *Metrosideros*/*Cheirodendron* rain forest, uluhe fern thickets with no tree canopy, strawberry guava monostands, *Eucalyptus* forest, *Schinus*/*Lantana* pasture, and dry *Leucaena*/*Panicum* shrubland (Table 1). The leaf litter at each site was derived from the dominant cover. Although the highest numbers (> 1.5/trap/day) were trapped in the wet forest of the Alaka'i, similarly high numbers (> 1.0/trap/day) were observed in the mesic *Acacia koa*

Table 1. Sampling localities for *Scaptomyza anomala* on Kaua'i.

Location	Sampling Period (mos.)	No. of traps	Rainfall (cm/yr)	Elev.(m)	Vegetation	Present(P) Absent(A)
Moloa'a	2	10	125	150	*Psidium guajavum*, *Psidium cattleianum*	A
Waikoko	1	10	350	340	*P. cattleianum*, *Metrosideros*, uluhe fern	P
Powerline	2	5	250	180	*P. cattleianum*, *Schinus*	P
Kaukaopua	3	5	250	100	Acacia koa, *Melaleuca*	P
Hanakapi'ai						
lower site	2	3	150	10	*Mangifera*, *P. cattleianum*	P
middle site	2	3	165	120	*P. guajavum*	P
upper site	2	4	175	210	*Aleurites*, *P. guajavum*	P
Kalaheo	2	10	125	150	cultivated coffee	A
Makaha	2	5	100	900	Acacia koa, *Styphelia*	P
Waimea						
site 1	1	5	100	1000	Acacia koa, *P. cattleianum*	P
site 2	1	5	90	600	*Schinus*, *P. guajavum*	P
site 3	2	5	60	300	*Leucaena*, *Panicum*	P
Plum Trail	2	10	250	1200	*Metrosideros*, *Cryptomeria*	P
Alaka'i	24	10	350	1200	*Metrosideros*, *Cheirodendron*, *Melicope*	P
Alexander Reservoir						
site 1	12	5	130	160	*Schinus*, *Lantana*, *Syzygium cumini*	P
site 2	12	5	130	300	*Eucalyptus*	P
site 3	12	5	160	425	*Eucalyptus*, *P. cattleianum*	P
site 4	12	5	200	510	*P. cattleianum*, *Metrosideros*, uluhe fern	P

forest on Makaha Ridge, and the *Schinus/Lantana* pasture at the Alexander Reservoir 160 m site.

The only sites where *S. anomala* was not found were the 2 agriculture areas, in the Kalaheo coffee field and Moloa'a. Thus its distribution does not seem to be limited by elevation or rainfall, but it may be excluded from areas that have experienced recent or frequent disturbance, although Hardy (1965) even reported it from a Maui pineapple field. The discovery of *S. anomala* in low elevation, non-native habitat adds to the observations of Montgomery (1975). He found that some Drosophilidae may not be particularly susceptible to alien predators such as the big-headed ant (*Pheidole megacephala* Fabricius), and that they constitute part of a small native fauna that has remained in (or recolonized) disturbed, lowland areas (Asquith & Messing 1993).

The wide occurrence of this species lends an obvious advantage to using it as a representative, since sites for monitoring its presence do not need to be located in native habitats, but could be selected based largely on accessibility, security and convenience. These are important factors in the maintenance of long-term monitoring. In addition, this species occurs in, or adjacent to, areas that could conceivably receive bait spray treatments. Coffee is now the primary host for the Mediterranean fruit fly on Kaua'i; Hanakapi'ai and similar valleys have extensive feral coffee, and the lower Alexander Reservoir site is with-

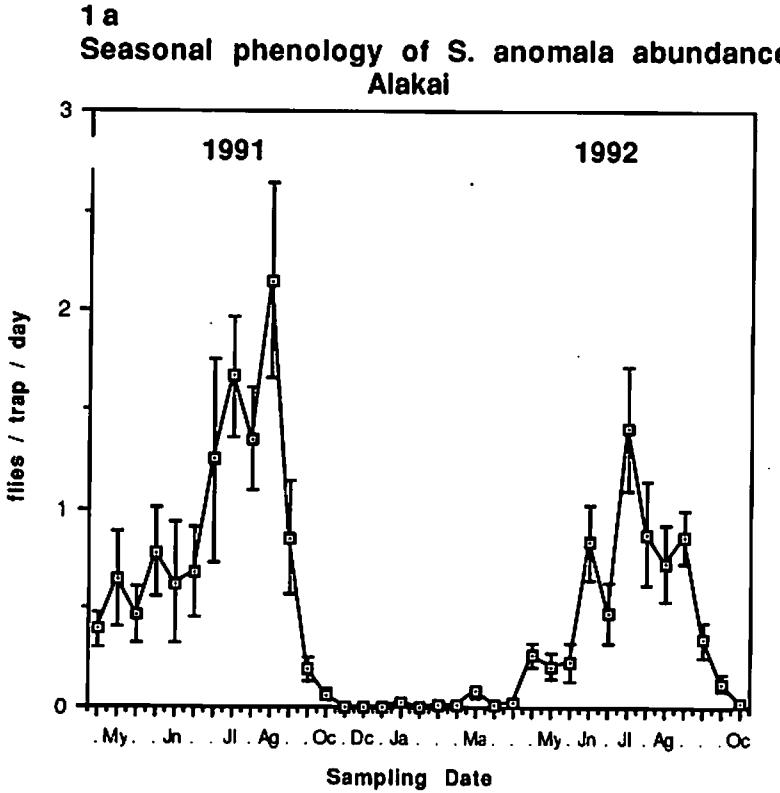

Fig. 1a. Seasonal changes in *Scaptomyza anomala* abundance in the Alaka'i Swamp on Kaua'i. Vertical bars are SE.

in 0.5 km of cultivated coffee fields.

Seasonality

Fly populations at the Alaka'i site showed strong seasonality, with numbers peaking from June to September in both years, and the fly essentially disappearing from November to April (Fig. 1a). This peak was negatively correlated with average monthly rainfall and positively correlated with average monthly temperature (Fig. 1b, Table 2). Although correlations were significantly negative, abundance corresponded poorly with the actual monthly rainfall, so that no obvious changes in fly numbers occurred with particularly high or low precipitation. This is probably because the humidity in the understory of the rainforest is constantly high and largely independent of daily rainfall (Craddock & Johnson 1981). These distinct, yearly oscillations in adult numbers suggest a life cycle tied to the predictable seasonal changes in rainfall and temperature, and not a facultative response to short term weather vacillations.

Seasonal phenology at Alexander Reservoir was more complicated and less distinct, with only 2 sites displaying clear seasonal patterns. Fly numbers at the 160 m site peaked from January–April and the fly essentially disappeared from May–December (Fig. 2). At the 300 m site, fly abundance peaked from January–May and was low or absent during the rest of the year (Fig. 3). The 425 m and 510 m sites had fluctuating low numbers from February –September and the fly was absent or barely detectable from October–January.

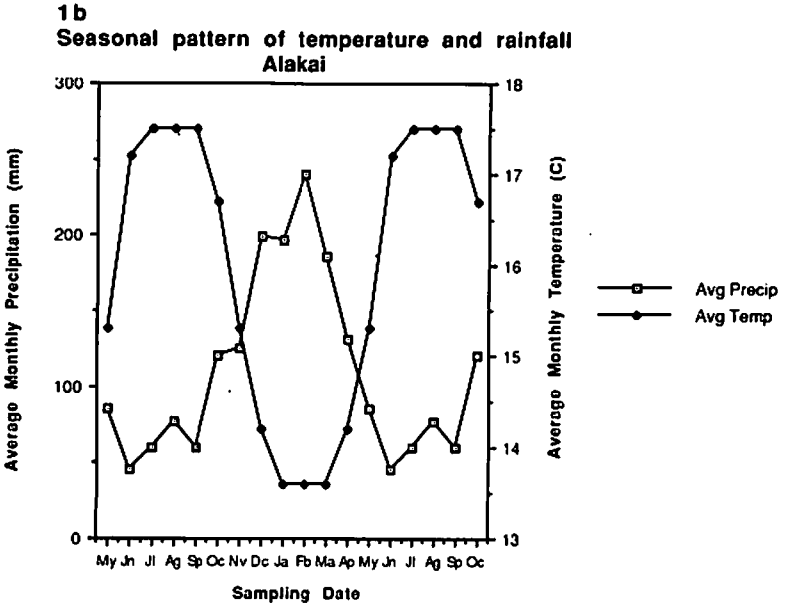

Fig. 1b. Seasonal variation in mean monthly temperature and precipitation at Kanalohuluhulu, near the Alaka'i Swamp, Kaua'i.

Table 2. Correlations between *Scaptomyza anomala* abundance and seasonal environmental factors recorded at Alaka'i and 4 elevations at Alexander Reservoir, Kaua'i, Hawai'i.

Elevation (m)	Statistical Parameter	Actual Monthly Precipitation	Average Monthly Precipitation	Average Monthly Temperature
Alaka'i				
1200	*F*	5.590	10.180	13.800
	P	0.033	0.007	0.002
	r^2	-0.285	-0.421	0.496
Alexander Reservoir				
160	*F*	0.020	0.060	20.560
	P	0.905	0.810	0.002
	r^2	0.002	0.007	0.719
300	*F*	3.000	3.960	5.510
	P	0.122	0.082	0.047
	r^2	0.273	0.330	-0.408
425	*F*	0.500	0.510	0.170
	P	0.500	0.490	0.690
	r^2	0.050	0.060	-0.021
510	*F*	1.370	0.060	0.860
	P	0.270	0.810	0.380
	r^2	0.146	0.008	0.097

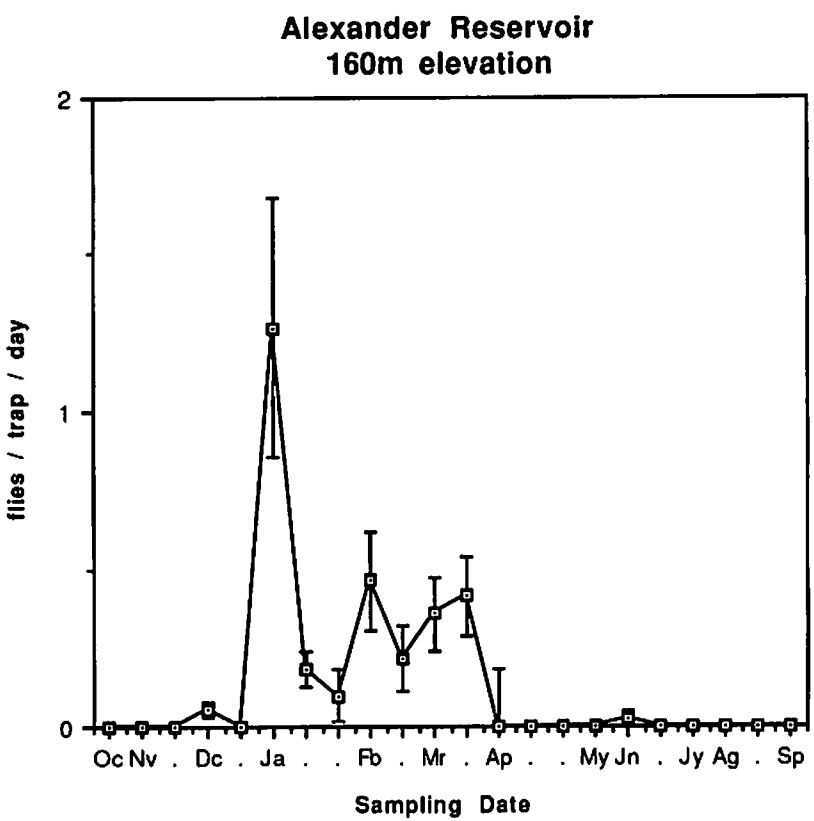

Fig. 2. Seasonal changes in *Scaptomyza anomala* abundance at the 160 m site at Alexander Reservoir. Vertical bars = SE.

At the Alexander Reservoir sites, fly abundance was never correlated with actual or average monthly precipitation (Table 2). Fly numbers at the 160 m and 300 m sites were both negatively correlated with temperature, in direct contrast to the Alaka'i population. This difference is probably partly attributable to fly activity being limited by low temperatures at high elevations and high temperatures at lower elevations, and thus the phenologies at the 2 sites are adjusted accordingly.

The phenology of Hawaiian insects has received little attention, possibly because seasonality is thought to be unimportant in tropical island systems (Howarth & Ramsay 1991). However, the endemic species of Sciaridae, *Ctenosciara hawaiiensis* (Hardy), displays seasonality at 1600 m elevation on the island of Hawai'i (Steffan 1981). In this insect, peak numbers were observed during the wettest months, from February–June, and populations did apparently respond to specific periods of high precipitation. Seasonal phenologies for native Hawaiian Drosophilidae have not been well documented, but of the 2 introduced species examined, *Drosophila simulans* Sturtevant showed strong seasonality whereas *D. immigrans* Sturtevant did not (Paik et al. 1981). Given the known responses of continental *Drosophila* Fallén to seasonal fluctuations in temperature and rainfall (Prakash & Reddy 1979, Ochando 1980, Yamamoto & Ohba 1984), even in tropical areas (David et al. 1984), the strong seasonality of *S. anomala* in the Alaka'i should not be sur-

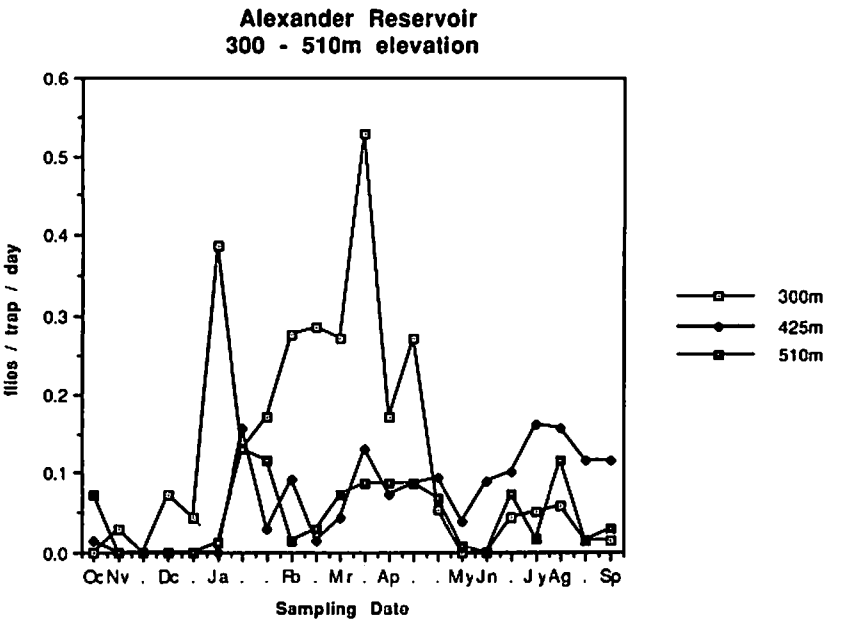

Fig. 3. Seasonal changes in *Scaptomyza anomala* abundance at the 300 m, 425 m, and 510 m sites at Alexander Reservoir. Vertical bars = SE.

prising. However, most Hawaiian *Drosophila* can be collected throughout the year, or at least during periods of weather favorable to their activity (Bill Perreira, pers. comm.). *Drosophila silvestris* (Perkins), for example, does not display seasonal patterns of abundance, but can be found throughout the year at 1650 m on Kilauea volcano on Hawai'i Island (Craddock & Johnson 1981), even though the mean daily temperature variation through the year shows the same pattern and almost the exact magnitude (4 °C) as the Alaka'i. Therefore, although the literature would suggest that the distinct seasonality of some *S. anomala* populations may be unusual among Hawaiian insects, preliminary data suggest that other litter inhabiting arthropods at the Alaka'i site may also be very seasonal, so that the extent of this phenomenon in the Hawaiian fauna should be examined more closely.

The seasonality of *S. anomala* has important implications for both bait spray programs and their environmental assessment. The fact that in some areas *S. anomala* may be inactive or absent as adults during part of the year suggests a window of time that this species may be less or non-susceptible to sprays. Troetschler (1983) suggested that seasonal timing of bait sprays might affect nontarget species differently, depending on their phenologies. These data also suggest that when monitoring *S. anomala* for the effects of a bait spray application, data taken before and after treatment within the same year may not suffice. The absence of the fly at the 160 m Alexander Reservoir site during July–November, for example, could not be attributed to a bait spray applied earlier in the year. Rather, the pretreatment seasonal peak during January–April should be compared to the same period the year following treatment. To further complicate monitoring, between year-variation in fly numbers was observed at the Alaka'i site. The peak May–October numbers in 1991 were 0.738/trap/day but only 0.551/trap/day in 1992 ($F = 11.37$, $P < 0.001$).

Variation in fly phenologies among sites and variation in fly abundance between years

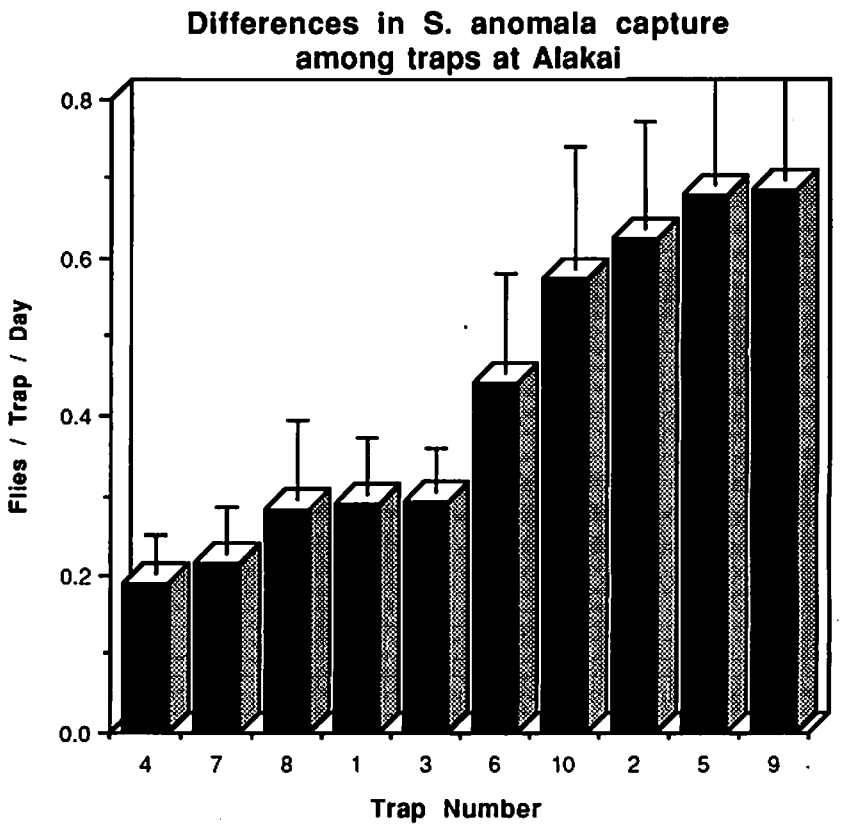

Fig. 4. Variation in *Scaptomyza anomala* caught among baited pitfall traps at the Alaka'i site. Traps were numbered sequentially, and positioned as three groups (1–5, 6–7, 8–10), so that numbers reflect trap proximity within a group. Traps within groups were 10–15 m apart. Groups were ca 100 m apart. Vertical bars = SE.

suggests that multiple, paired treatment and control sites would be required to accurately assess any treatment effects. Multiple year post-treatment monitoring of sites is also suggested since the recovery of arthropod communities after bait sprays is often complete and rapid (Ehler & Kinsley 1991, Quinn et al. 1991), and the temporary suppression of *S. anomala* populations would probably not be as objectionable as would be its permanent extirpation from an area.

Trapping

Variation in fly numbers among traps at a site was high, with coefficients of variation (100(SD)/mean, Simpson et al. 1960) ranging from 49.0–108.9 in the Alaka'i traps during the peak summer months (June–September), and from 65.7–187.2 at the various Alexander Reservoir sites. This variation among traps means that a fairly large number of traps would be required to accurately assess the fly population at a given location. At the Alaka'i site, for example, 100–200 traps would be necessary to measure the population size with an accuracy of 0.05 SE ($n = (s/X(0.05))^2$, where s = standard deviation and X = mean; Southwood 1978). However, estimating the real population size is not a requirement for a monitoring program, and the use of pitfall traps, particularly baited ones, is a

Table 3. Correlations between *Scaptomyza anomala* abundance and environmental factors of individual trap location.

Location	Environmental Factor	Correlation Coefficient (r)	Probability
Alaka'i	Litter	0.183	> 0.5
	Shade	-0.786	< 0.01
	Direct Light	0.538	$0.1 > P > 0.05$
	Moisture	-0.048	> 0.5
Alexander Reservoir	Litter	-0.098	> 0.5
	Shade	0.319	$0.1 > P > 0.05$
	Direct Light	-0.296	0.01
	Moisture	-0.181	> 0.5

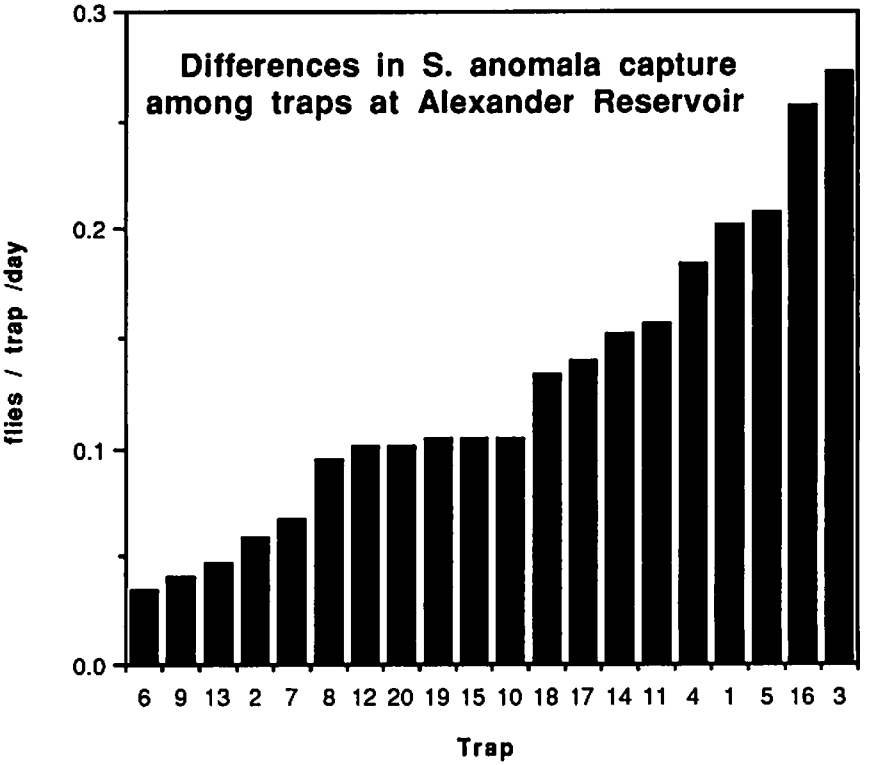

Fig. 5. Variation in *Scaptomyza anomala* caught among baited pitfall traps at the Alexander Reservoir site. Traps were numbered sequentially, and positioned as three groups (1–5, 6–10, 10–15, 16–20), so that numbers reflect trap proximity within a group. Traps within a group were 10–20 m apart. Groups were ca 0.5 km apart.

relative rather than absolute sampling method (Southwood 1978). The objective of a monitoring method for bait spray assessment should be to quantify any differences there might be in the relative numbers of flies caught before and after a spray, or between sprayed and unsprayed areas. Treating each sampling period as a distinct experiment increases the sample size without increasing the number of traps installed (see Asquith & Messing 1992). This design provided sample sizes large enough to discern differences between years at the Alaka'i site (see above) and among sites at Alexander Reservoir ($F = 6.37$, $P = 0.0003$). Thus, 5–10 traps sampled (rebaited) per site weekly or biweekly should provide an adequate assessment of the relative numbers of *S. anomala* for a monitoring program.

There were also significant differences among individual trap catches at the Alaka'i site ($F = 7.5$, $P < 0.001$) with a 3-fold difference between the highest and lowest catches (Fig. 4). The proximity of traps was not indicative of comparative fly numbers. For example, traps #2 and #3 were within 10 m of each other yet catches differed by 2 fold. Even greater differences were observed at Alexander Reservoir ($F = 1.89$, $P = 0.014$) where at the 160 m site, adjacent traps #2 and #3, also 10 m apart, differed by 5-fold (Fig. 5). Similar differences in abundance between and within sampling locations was observed for *Drosophila phalerata* breeding in fungal fruiting bodies in England (Shorrocks 1982), though in this case, a gradient of fly density was observed across the sampling location, rather than the mosaic pattern displayed by *S. anomala*. Sharp changes in the presence/absence or abundance over very small distances has also been observed in other Hawaiian *Drosophila* (K.Y. Kaneshiro, pers. comm.), but in general, adult Hawaiian *Drosophila* abundance is not often quantified.

Fly abundance was not correlated with the amount of leaf litter or soil moisture at either site (Table 3). At the Alaka'i site, more flies were caught in traps with less shade and some direct sun light, in contrast to Alexander Reservoir, where abundance was positively, although weakly, correlated with the amount of shade (Table 3). I interpret this pattern as reflecting the opposite temperature extremes experienced by the flies at the 2 locations. At the high elevation Alaka'i site, low temperatures probably limit fly activity, so that either individuals seek, or populations become larger, in warmer, sunnier spots. At lower, drier elevations like Alexander Reservoir, high daytime temperatures and the associated increase in water loss potential, may make areas with direct sun less suitable to fly activity.

The implication of these patterns for a monitoring program is that multiple paired traps, or groups of traps in treatment and control areas, should be placed in similar microhabitats to reduce the among trap variation in fly numbers.

CONCLUSIONS

Scaptomyza anomala is strongly attracted to protein bait, and is ubiquitous on Kaua'i, occurring in or near areas likely to receive bait spray treatments if this technique is deemed necessary in Hawai'i. It can be easily sampled using protein baited pitfall traps and is a distinctive, shiny black species that can be easily recognized in samples. In high elevation forest on Kaua'i it is very similar to its congener *Scaptomyza hamata* Hardy, but in over 2 years of sampling, this latter species was never collected in pitfall traps. At low elevations, *S. anomala* can be confused only with certain small Sphaeroceridae, but I have trained non-specialists to differentiate between these, so that samples can be sorted and processed without the need of a trained taxonomist.

Five to 10 pitfall traps sampled repeatedly over time is probably sufficient to measure relative fly abundance in any particular area. Servicing 5–10 traps requires 15–30 min. of field work and an additional 30–60 min. of sorting in the laboratory. Thus with a mini-

mum amount of equipment, time, and expertise, this species could be used to monitor the effects of a bait spray program. Because of the variation in fly abundance between microhabitats and sampling locations, it is suggested that any monitoring program use multiple traps in each of several paired, treatment and control sites, with attention to similar microhabitat placement of traps. Furthermore, sampling should be conducted a minimum of 1 year before and 1 year after a treatment so as to account for expected seasonal fluctuations in fly abundance.

I have chosen not to discuss *S. anomala* as an indicator species because of the somewhat semantic question of what exactly a change in its abundance would indicate. In most monitoring programs, a particular species might be used because it is especially sensitive to some perturbation and functions as an early warning, or the species is a clear representative of a certain ecosystem quality or a community (Thomas et al. 1973, Peterken 1974, Vos et al. 1985). *Scaptomyza anomala* might be monitored simply because it is attracted to the protein bait, but this does not necessarily mean that this species would be affected by a bait spray treatment. However, this problem is unavoidable since monitoring is, by nature, *post hoc* information gathering and not predictive. But a better understanding of the potential susceptibility of *S. anomala* could be provided by small field trials conducted to demonstrate reduction in fly numbers following bait spray applications.

However, even with this information, monitoring *S. anomala* numbers would only indicate the probable health of this species alone in any particular area. Its wide habitat distribution precludes it from functioning as a community indicator. It is likely that ecologically similar species (e.g., other leaf litter-breeding *Drosophila*, Asquith & Messing 1992) would respond comparably to bait spray treatments, but because of the relative scarcity of most other native species, quantifying a relationship between the reduction of *S. anomala* and other endemics is not practical, or even advisable due to the potential impact of the required experiment itself.

Given these caveats, I suggest *S. anomala* be viewed as a "representative" native species rather than a true indicator. In addition, *S. anomala* as adults, and most probably as larvae, inhabit the ground litter, and should be used as a representative organism only for the rest of the litter inhabiting arthropod community. Other representative species (e.g., endemic crickets or psocids) should be identified and monitored for assessing an impact on the arboreal community.

The fundamental goal of any biological monitoring program is to provide feedback for consideration in future decision making (Keddy 1991). Thus the information obtained from monitoring representative species such as *S. anomala* during and after small-scale or trial bait spray treatments should be used in helping to decide to expand, restrict or eliminate bait sprays for fruit fly eradication in Hawai'i. In California, emergency use of bait sprays usually disallows the establishment of preferred monitoring measures (Troetschler 1983), and what to monitor may be decided by serendipitous pre-treatment research programs (Ehler et al. 1984). Hawai'i, on the other hand, has the opportunity to develop unparalleled protocols for assessing eradication impacts on native nontarget arthropods to complement its long history of successful agricultural pest control.

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